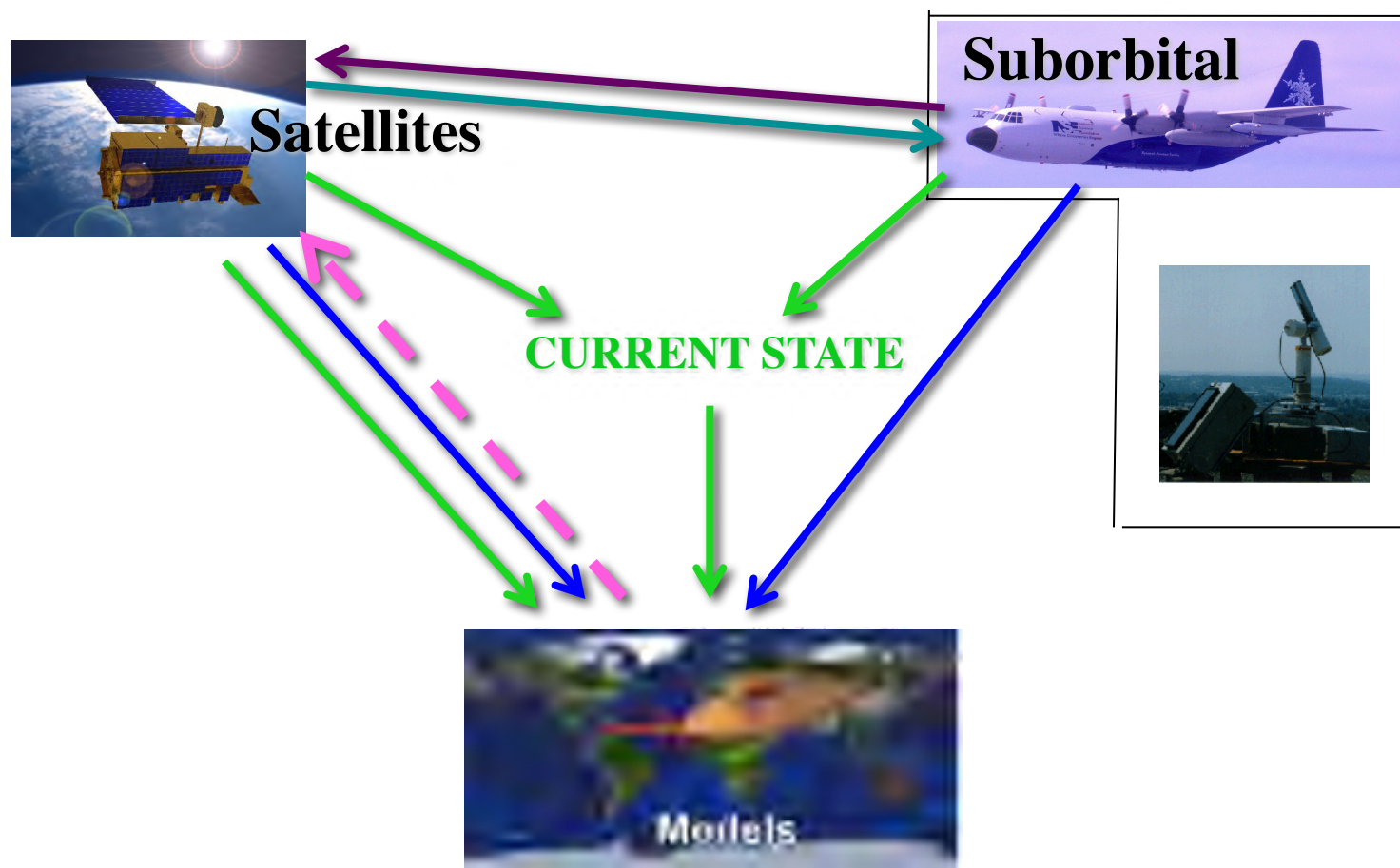


# Aerosol Concentration, Size, Hygroscopicity, & MEE, Globally: What do we need to know, and how can we know it?

***Ralph Kahn*** *NASA Goddard Space Flight Center*



# What We Need, Globally

- Aerosol **AMOUNT** (AOD – 2D)
- Aerosol **VERTICAL DISTRIBUTION**
- Aerosol “**TYPE**”
  - **Light Absorption** (*direct forcing*)
  - **Hygroscopicity** (*interpreting AOD; indirect forcing*)
  - **Composition**  
(*source attribution;  $\mu$ -physical properties; mass flux*)
  - **Mass Extinction Efficiency (MEE)**  
(*measurement  $\leftrightarrow$  model translation*)

# What We Have...

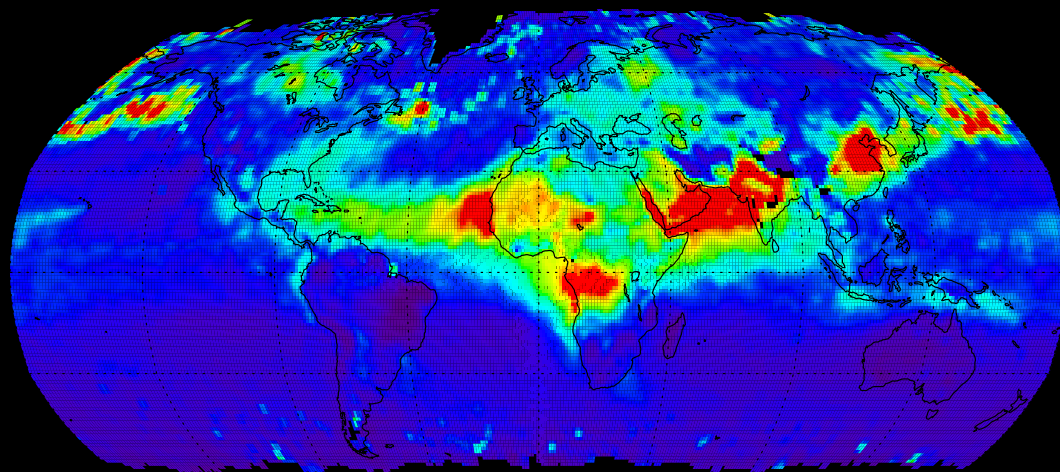
## AeroCom Experiment “A” Values

Quantity	Mean	Median	Range	Stddev /mean <sup>a</sup>
<b>Sources (Tg yr<sup>-1</sup>)</b>				
Sulfate	179	186	98-232	22%
Black carbon	11.9	11.3	7.8-19.4	23%
Organic matter	96.6	96.0	53-138	26%
Dust	1840	1640	672-4040	49%
Sea salt	16600	6280	2180-121000	199%
<b>Removal rate (day<sup>-1</sup>)</b>				
Sulfate	0.25	0.24	0.19-0.39	18%
Black carbon	0.15	0.15	0.066-0.19	21%
Organic matter	0.16	0.16	0.09-0.23	24%
Dust	0.31	0.25	0.14-0.79	62%
Sea salt	5.07	2.50	0.95-35.0	188%
<b>Lifetime (day)</b>				
Sulfate	4.12	4.13	2.6-5.4	18%
Black carbon	7.12	6.54	5.3-15	33%
Organic matter	6.54	6.16	4.3-11	27%
Dust	4.14	4.04	1.3-7.0	43%
Sea salt	0.48	0.41	0.03-1.1	58%
<b>Mass loading (Tg)</b>				
Sulfate	1.99	1.98	0.92-2.70	25%
Black carbon	0.24	0.21	0.046-0.51	42%
Organic matter	1.70	1.76	0.46-2.56	27%
Dust	19.2	20.5	4.5-29.5	40%
Sea salt	7.52	6.37	2.5-13.2	54%
<b>MEE at 550 nm (m<sup>2</sup> g<sup>-1</sup>)</b>				
Sulfate	11.3	9.5	4.2-28.3	56%
Black carbon	9.4	9.2	5.3-18.9	36%
Organic matter	5.7	5.7	3.7-9.1	26%
Dust	0.99	0.95	0.46-2.05	45%
Sea salt	3.0	3.1	0.97-7.5	55%
<b>AOD at 550 nm</b>				
Sulfate	0.035	0.034	0.015-0.051	33%
Black carbon	0.004	0.004	0.002-0.009	46%
Organic matter	0.018	0.019	0.006-0.030	36%
Dust	0.032	0.033	0.012-0.054	44%
Sea salt	0.033	0.030	0.02-0.067	42%
<b>Total AOT at 550 nm</b>	<b>0.124</b>	<b>0.127</b>	<b>0.065-0.151</b>	<b>18%</b>

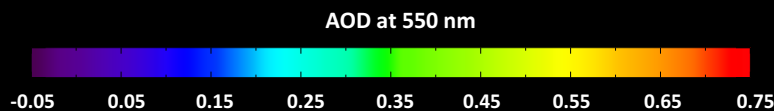
<sup>a</sup> Stddev/mean was used as the term “diversity” in Textor et al., 2006.

**MEE Ranges**  
**Factors of 3 – 6**  
**or more!**

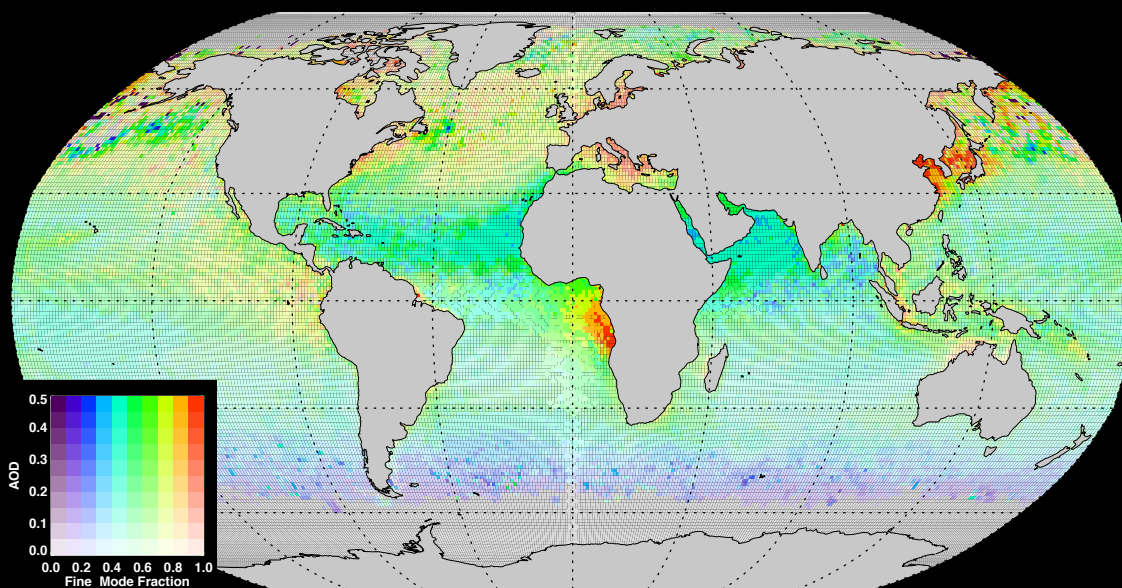
MODIS  
July 2010  
Monthly Average



Mid-Visible  
**AOD**  
“Dark Target” + “Deep Blue”



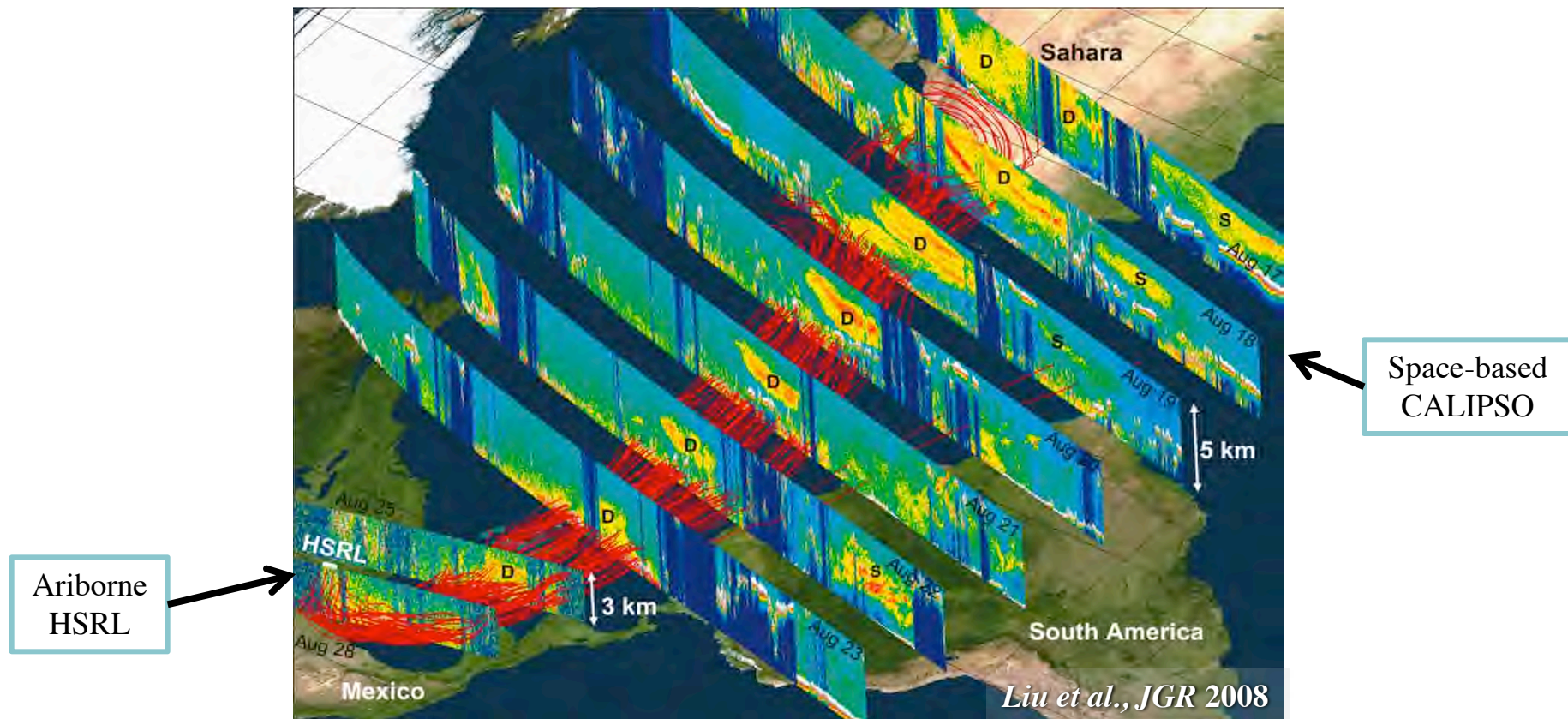
- Water & some Land
- Globe ~ **Every 2 days**
- ~ 10:30 AM & 1:30 PM



- **Fine/Coarse** Ratio  
Over Water + AOD
- Sensitivity to **PM10**



# Aerosol Sources, Processing, Transports, Sinks: **Lidar + Model**



**August 2007 Saharan dust “D” and smoke “S” event**  
mapped by CALIPSO 532 nm backscatter, with superposed  
model back trajectories and airborne HSRL observations

Piecing together the bigger picture. Consistency requires –

- An understanding of the *mechanisms* governing aerosol evolution
- Adequately constrained *initial & boundary* conditions

# Multi-angle Imaging SpectroRadiometer



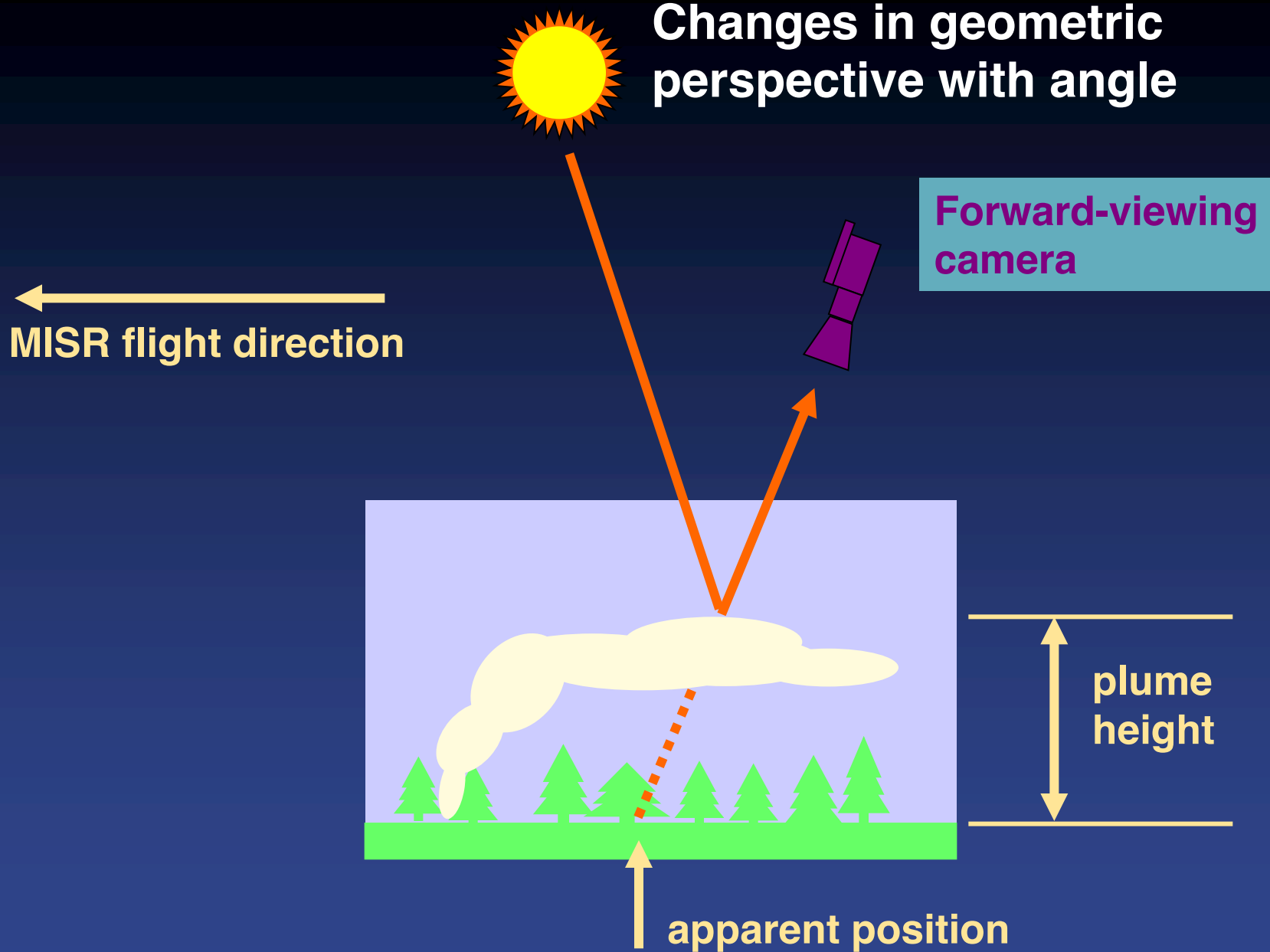
<http://www-misr.jpl.nasa.gov>

<http://eosweb.larc.nasa.gov>

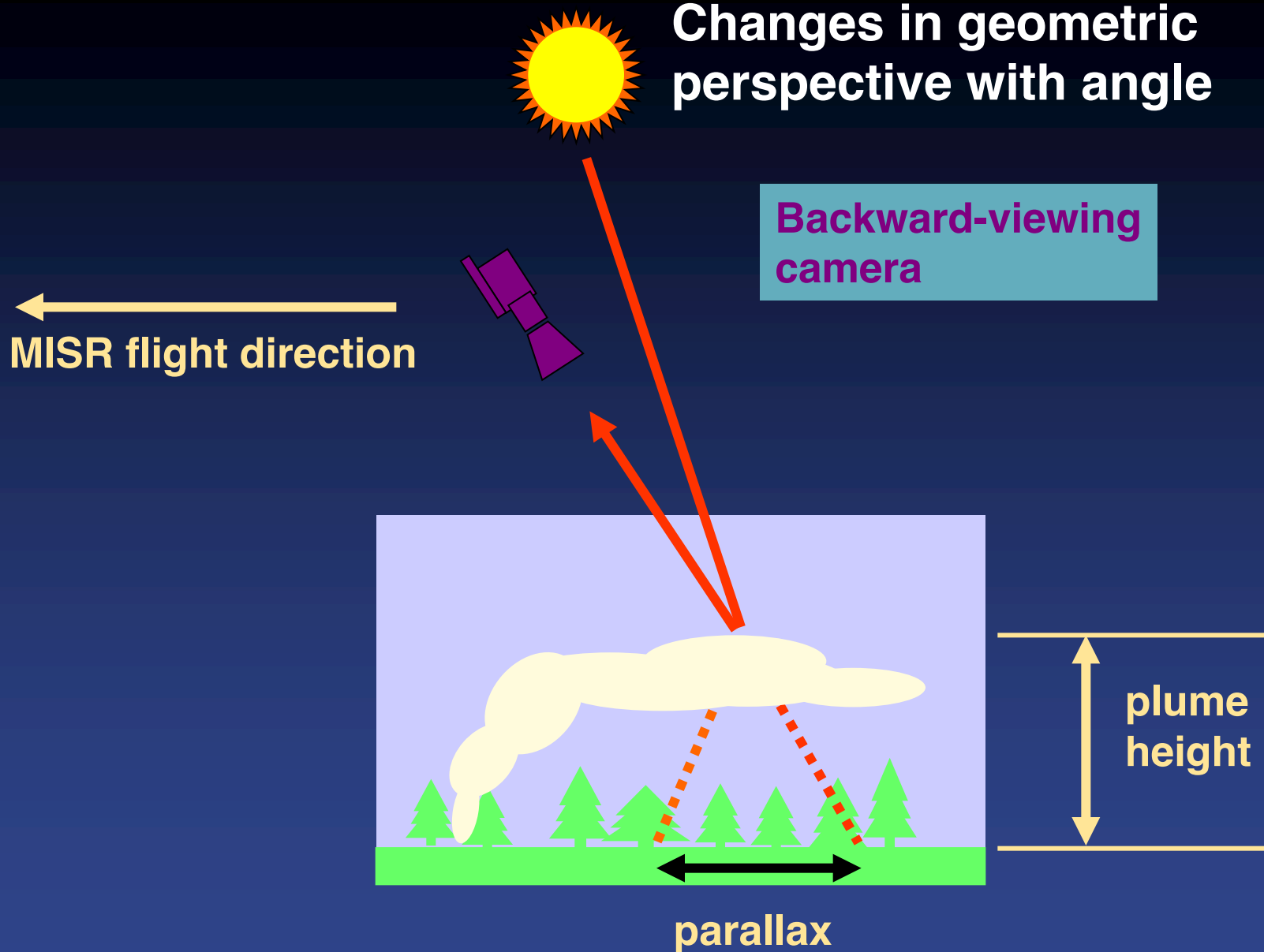
- Nine CCD push-broom cameras
- Nine view angles at Earth surface:  
70.5° forward to 70.5° aft
- Four spectral bands at each angle:  
446, 558, 672, 866 nm
- *Studies Aerosols, Clouds, & Surface*



# Changes in geometric perspective with angle



# Changes in geometric perspective with angle



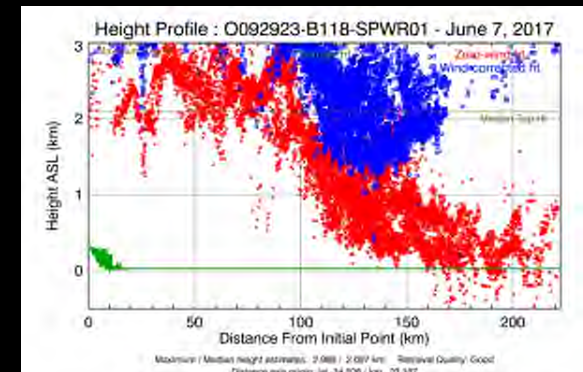
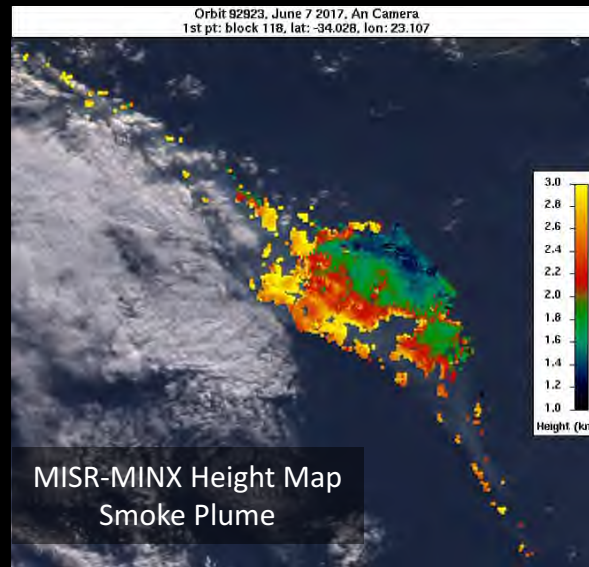


# Wildfire Outbreak in Knysna, South Africa

## MISR Active Aerosol Plume-Height (AAP) Project 7 June 2017

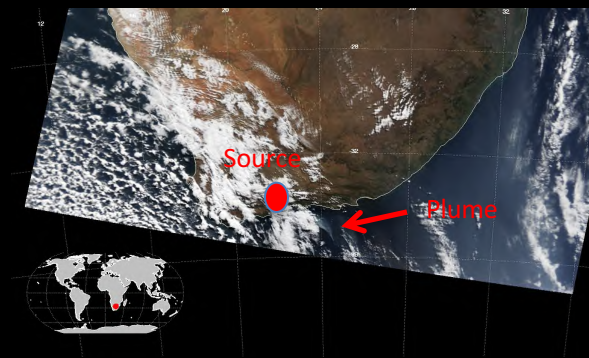
**Wildfire outbreaks** can generate a significant amount of atmospheric aerosols that can have **regional to global impacts** on Earth's energy balance and surface temperature. To determine the influence of wildfires, **accurate plume heights** are needed, but are **difficult to obtain in areas of significant cloud cover**. Stereo images from NASA's Multi-Angle Imaging Spectroradiometer (**MISR**) make it possible to retrieve plume heights using parallax by constraining the smoke plume layer height. When the retrieval height is significantly below the Lifting Condensation Level (**LCL**), the effects of cloud contamination are often reduced.

The **Knysna Wildfire** began the evening of June 6, 2017 and by June 07, consisted of **26 fires**. These fires were fanned towards residential areas by strong winds from a cyclone to the west. The towns of Belvidere, Brenton-on-Sea, and Rheenendal were evacuated after news that a family of three passed away in the fire on June 6. The smoke observed by MISR on June 7 was injected at **3+ km**. At this height, the aerosols can escape the boundary layer and enter the middle Troposphere, causing enhanced **regional cooling** and increased **long-range aerosol transport**.



### Zero-wind & Wind-Corrected MISR Height Profiles Downwind from Near-source

Aerial photograph from June 7  
(SA Red Cross Air Mercy Services)



MODIS image – 7 June 2017



CJ Vernon / U. Maryland  
R. Kahn / NASA GSFC

# Why We Care About *Aerosol Air Mass Type*

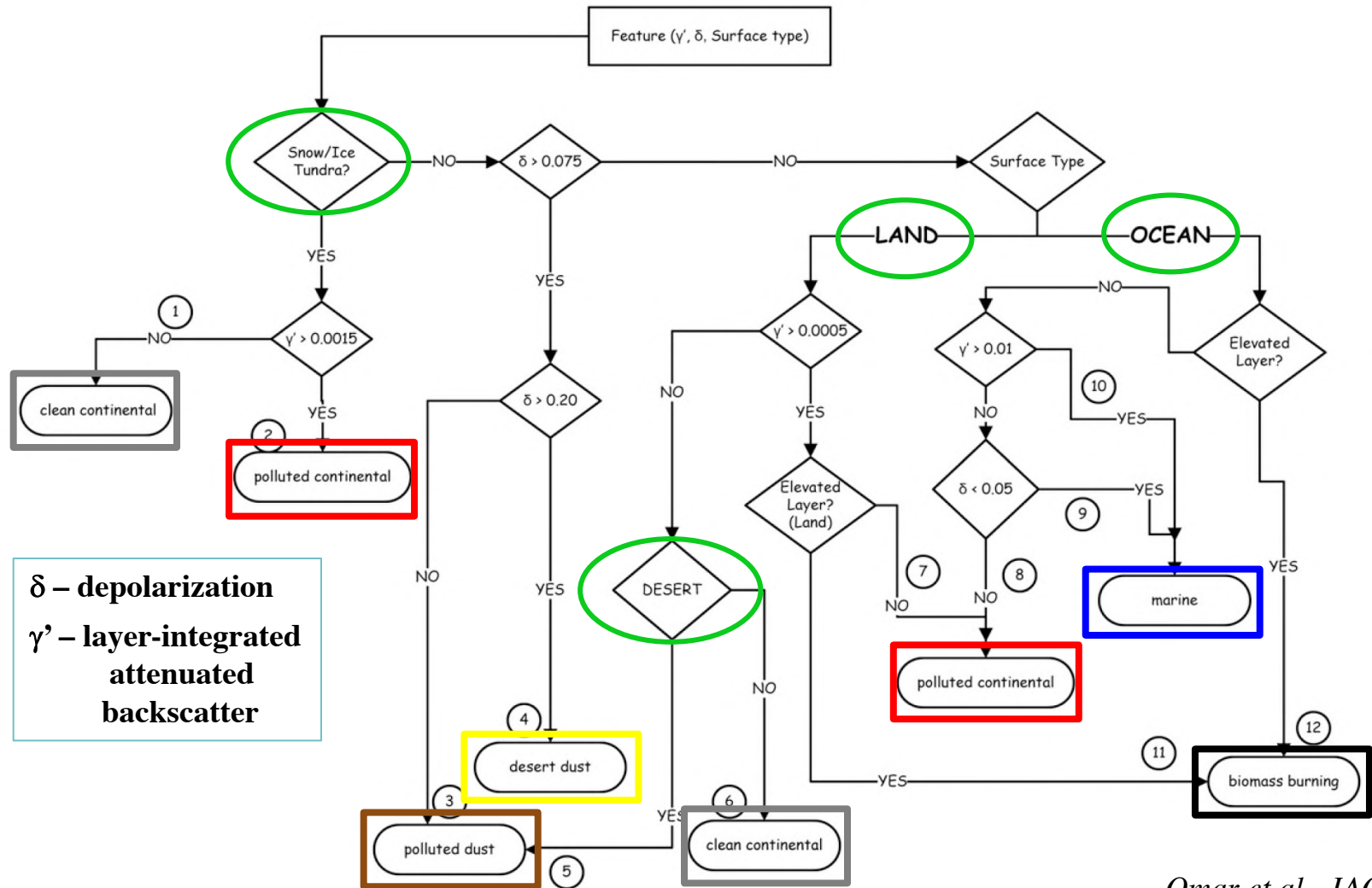
*Some applications* of satellite-mapped aerosol type, especially when *combined with* otherwise-constrained, detailed particle properties:

- ***Source Attribution***
- Mapping 3-D ***Aerosol Absorption*** that mediates impacts on ***atmospheric stability structure*** and can affect *convection*, *cloud evolution*, and *larger-scale atmospheric circulation*
- Mapping ***Particle Hygroscopicity*** required to account for humidity-dependent ***particle optical property changes*** as well as ***particle activation conditions*** that initiate cloud formation
- Deducing ***Mass Extinction Efficiency*** (MEE) distributions, required to ***constrain & validate air quality***, ***aerosol-transport***, and ***climate model*** aerosol mass with remote-sensing-derived particle *optical* properties.

*Aerosol Air Mass Type* derived from remote sensing can provide ***2-D and 3-D mapping required*** for many of these applications.

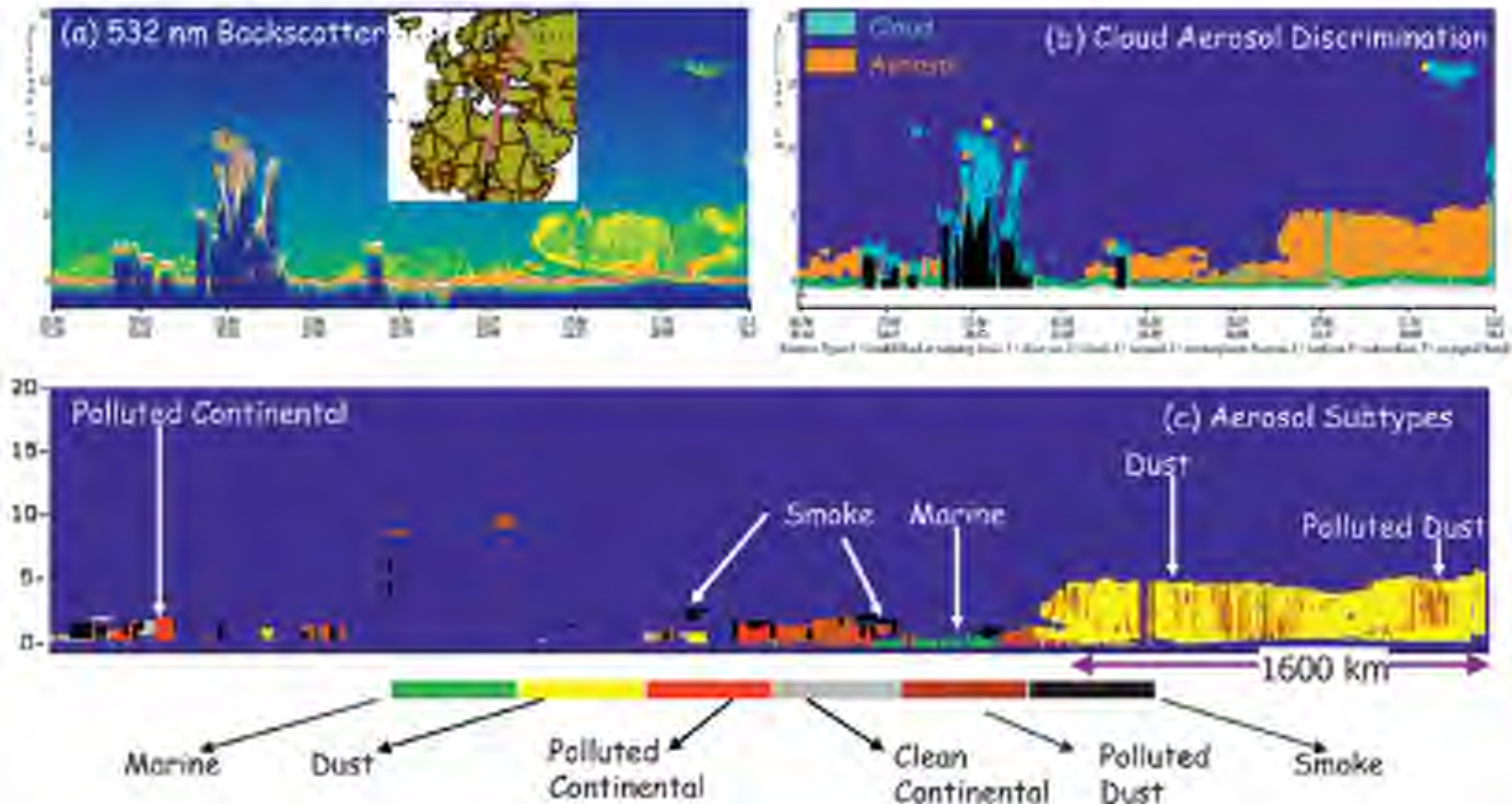
# Progress Toward a Global Aerosol Type Climatology

## CALIPSO Classification Scheme





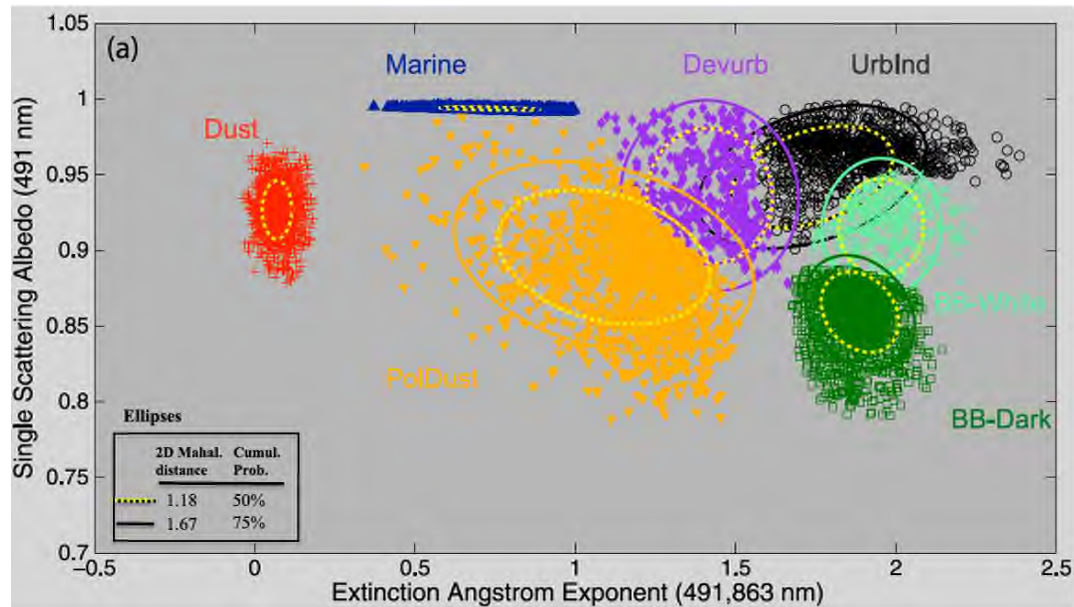
# ***CALIPSO* 6-Grouping Aerosol Type Classification**



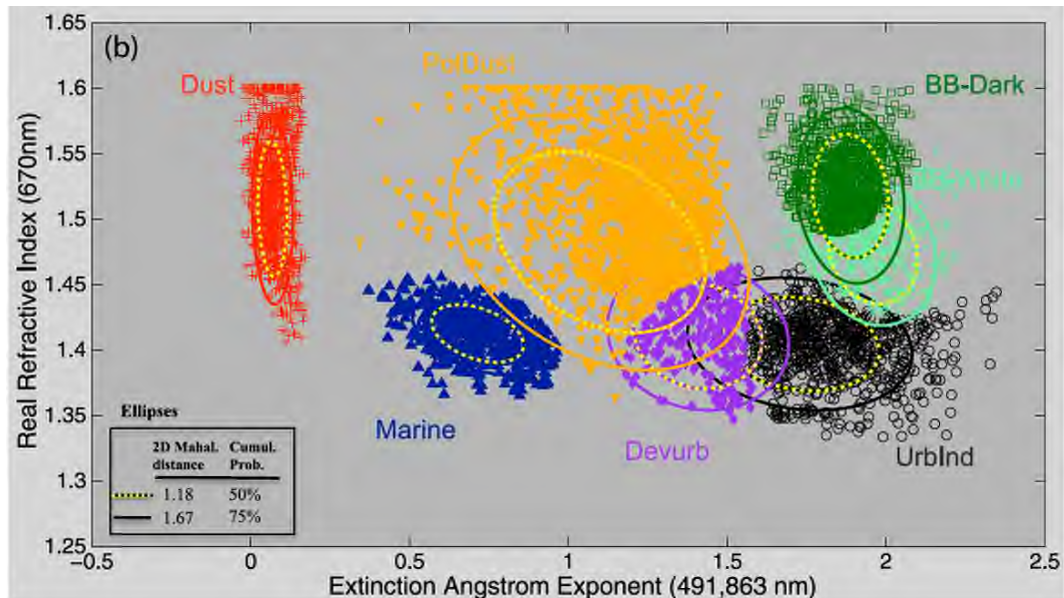
# **AERONET** Aerosol Type 7-Grouping Classification

Four-parameter  
AERONET-  
derived  
classification:

- $EAE_{491,863}$
- $SSA_{491}$
- $RRI_{670}$
- $dSSA_{863-491}$

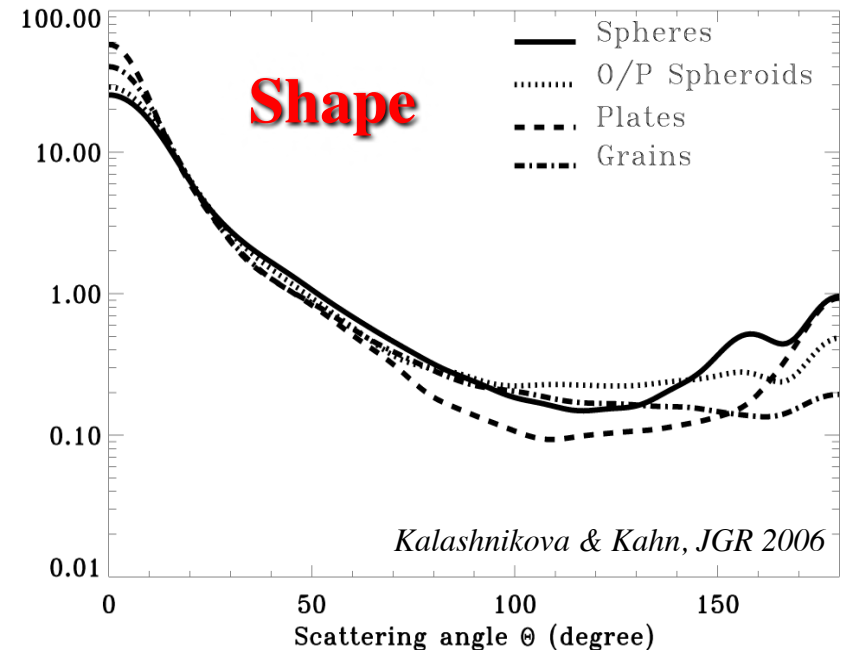
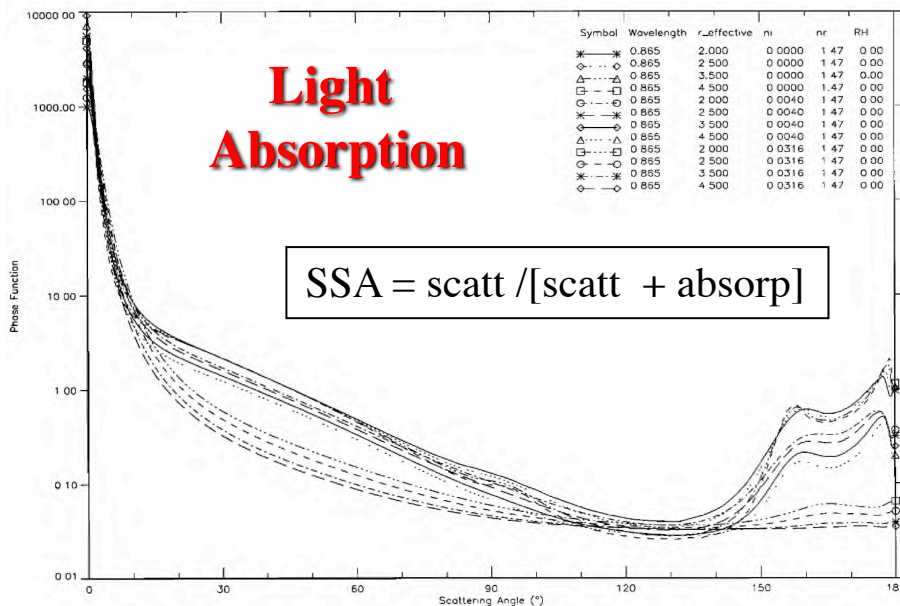
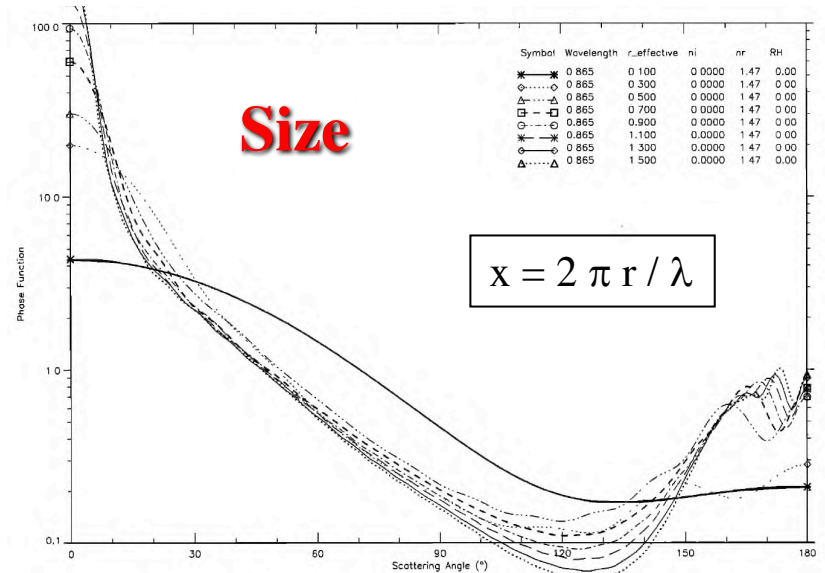
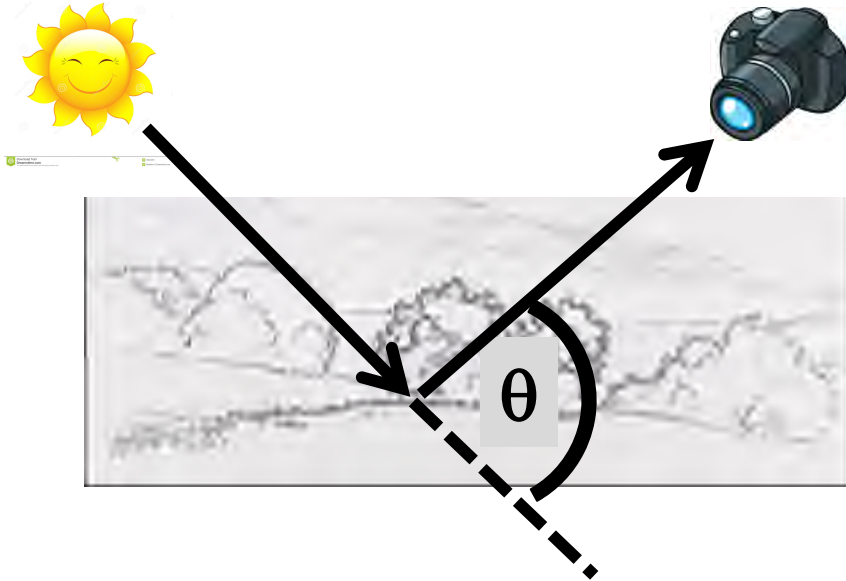


7 Groupings  
 $SSA_{491}$  vs.  
Extinction ANG



7 Groupings  
Real  $RI_{670}$  vs.  
Extinction ANG

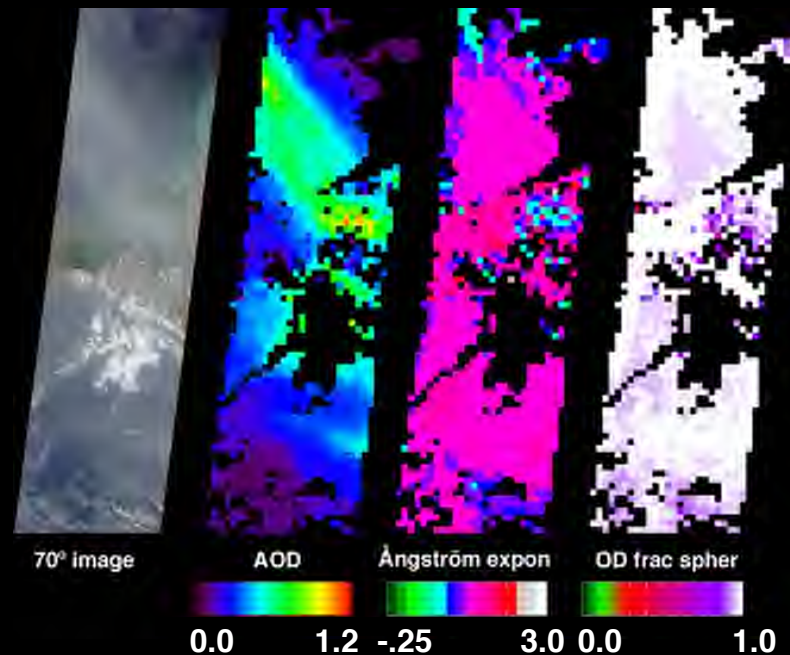
# Single-scattering Phase Functions for **Different Particle Properties**





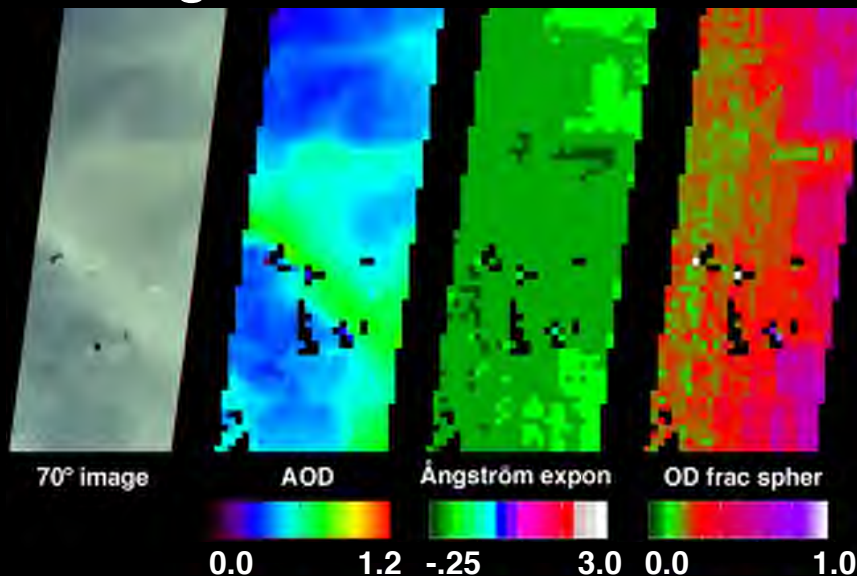
## Smoke from Mexico -- 02 May 2002

Aerosol:  
Amount  
Size  
Shape



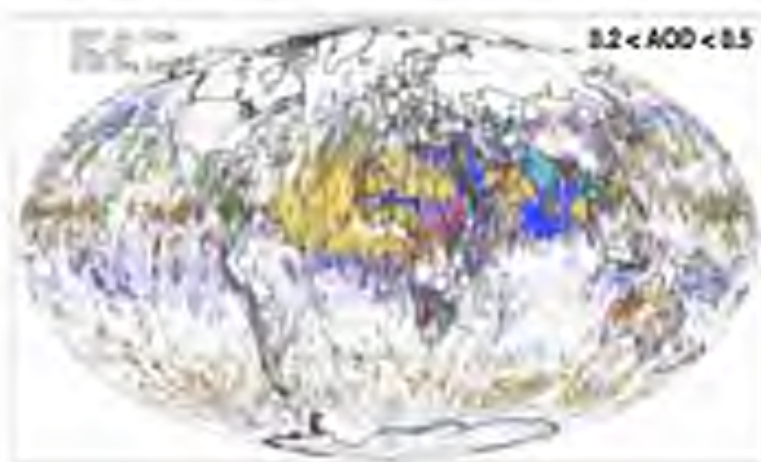
Medium  
Spherical  
Smoke  
Particles

## Dust blowing off the Sahara Desert -- 6 February 2004

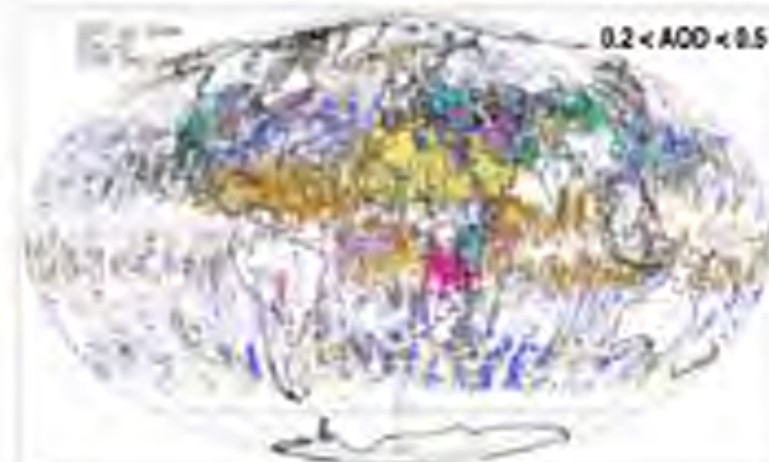


Large  
Non-Spherical  
Dust  
Particles

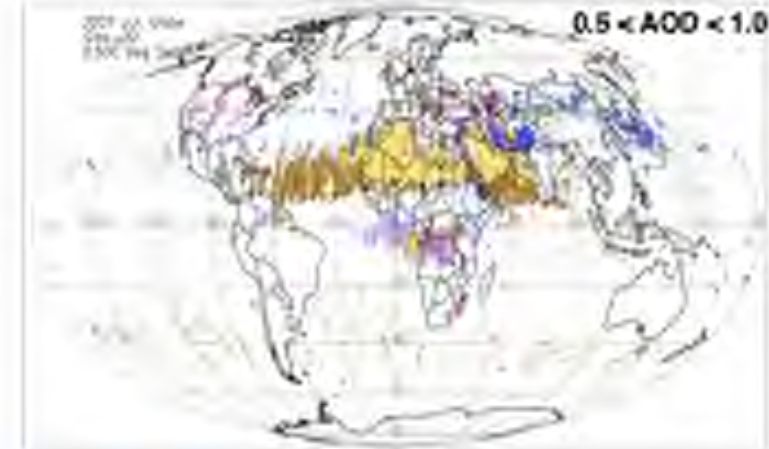
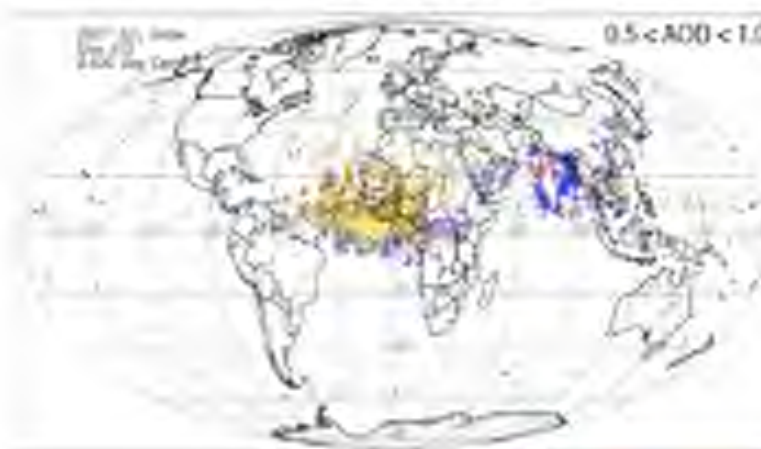
# ***MISR*** Aerosol Type Discrimination



**January 2007**



**July 2007**



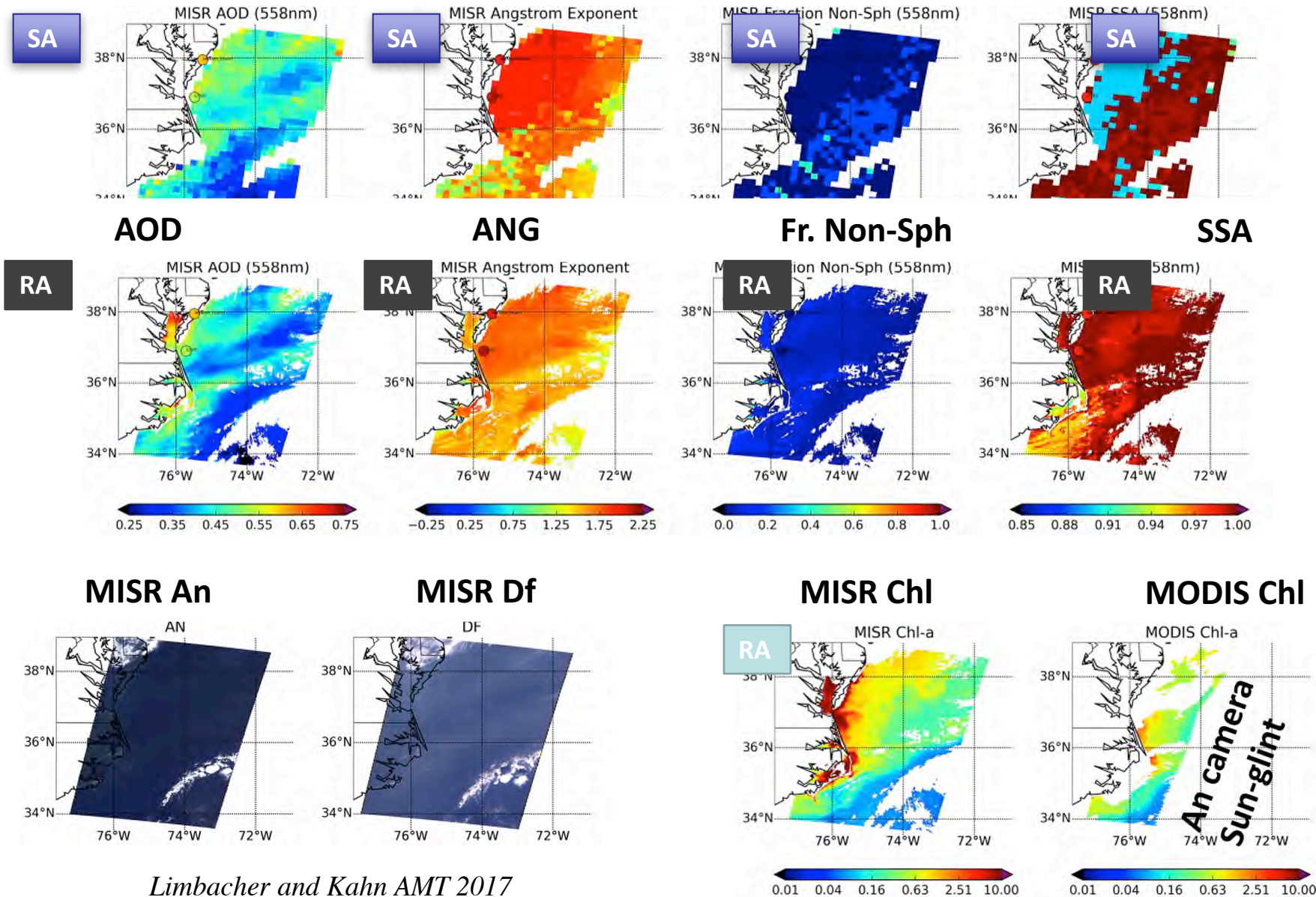
*Spherical, non-absorbing*

*Non-spherical*

*Spherical, absorbing*



# MISR *Research Algorithm* With Self-consistent Ocean Surface Retrieval





## Satellite *Aerosol Type* Summary

- Remote-sensing can provide optical constraints interpreted as particle *Size, Shape, and Indices of Refraction*
- A *further* interpretative step, entailing additional assumptions, reports particle *Chemical Composition*
- Remote-sensing *sensitivity to particle properties is much more dependent than AOD on retrieval conditions* (*Not* straightforward to provide quantitative uncertainty estimates)
- *Validation Data* for aerosol type are *very limited*
  - *Model simulations* and *In Situ measurements* can help



## Satellites

frequent, global  
snapshots;  
aerosol amount &  
aerosol type maps,  
plume & layer heights

Aerosol-type  
Predictions;  
Meteorology;  
Data integration

## Model Validation

- Parameterizations
- Climate Sensitivity
- Underlying mechanisms

Must *stratify* the global satellite  
data to treat appropriately  
situations where **different**  
**physical mechanisms** apply

## Remote-sensing Analysis

- Retrieval Validation
- Assumption Refinement

## Regional Context

## CURRENT STATE

- Initial Conditions
- Assimilation

## Suborbital



targeted chemical &  
microphysical detail



point-location  
time series



## Models

space-time interpolation,  
**Aerosol Direct &  
Indirect Effects**  
calculation and prediction

# SAM-CAAM

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]



[This is currently a *concept-development effort*, not yet a project]

## Primary Objectives:

- Interpret and *enhance ~17 years of satellite aerosol retrieval* products
- *Characterize statistically particle properties* for major aerosol types globally, to provide detail unobtainable from space, but needed to *improve*:
  - Satellite aerosol *retrieval algorithms*
  - The *translation between satellite-retrieved aerosol optical properties and species-specific aerosol mass and size tracked in aerosol transport & climate models*



# SAM-CAAM *Concept*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

- *Dedicated Operational Aircraft* – routine flights, 2-3 x/week, on a continuing basis
- *Sample Aerosol Air Masses* accessible from a given base-of-operations, then move; project science team to determine schedule, possible field campaign participation
- Focus on *in situ measurements required* to characterize particle *Optical Properties* (esp. *Light Absorption*), *Composition*, *Hygroscopicity*, and *Mass Extinction Efficiency*
- *Process Data Routinely* at central site; instrument PIs develop & deliver algorithms, upgrade as needed; data distributed via central web site
- Peer-reviewed paper to identifying *4 Payload Options*, of varying ambition; subsequent selections based on agency buy-in and available resources

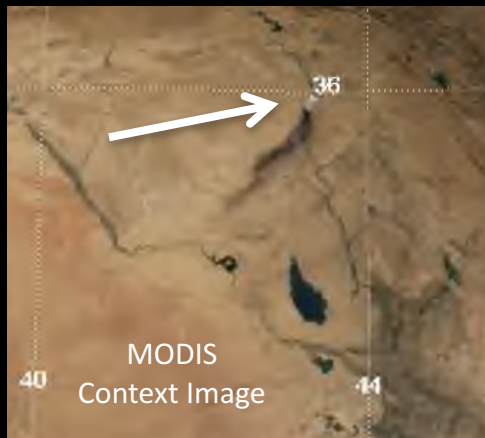
SAM-CAAM is feasible because:

Unlike aerosol amount, *aerosol microphysical properties tend to be repeatable* from year to year, for a given source in a given season

# Iraq's Mishraq Sulfur Plant and Oil Well Smoke Plume Heights

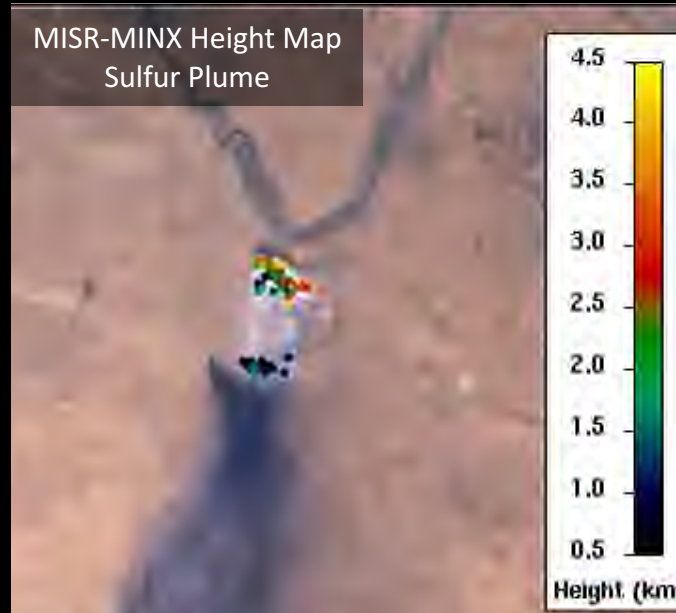
**MISR Active Aerosol Plume-Height (AAP) Project 21 October 2016**

The **height** at which smoke is injected into the atmosphere affects **how long** it will stay aloft, **how far** it will travel, and **how much of an impact** it will have on air quality downwind, and regional climate. In **northern Iraq**, at least two people have lost their lives, up to 1000 hospitalized, and 200 families evacuated from their homes due to sulfur & smoke pollution.

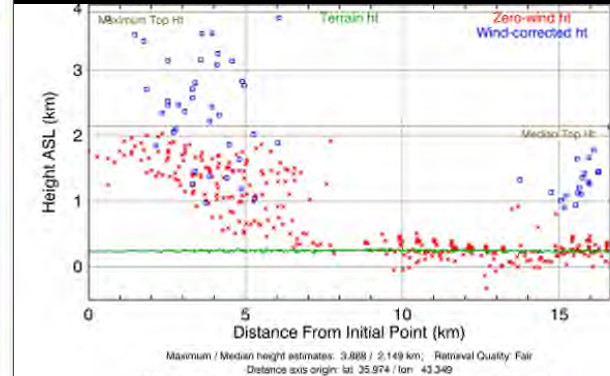
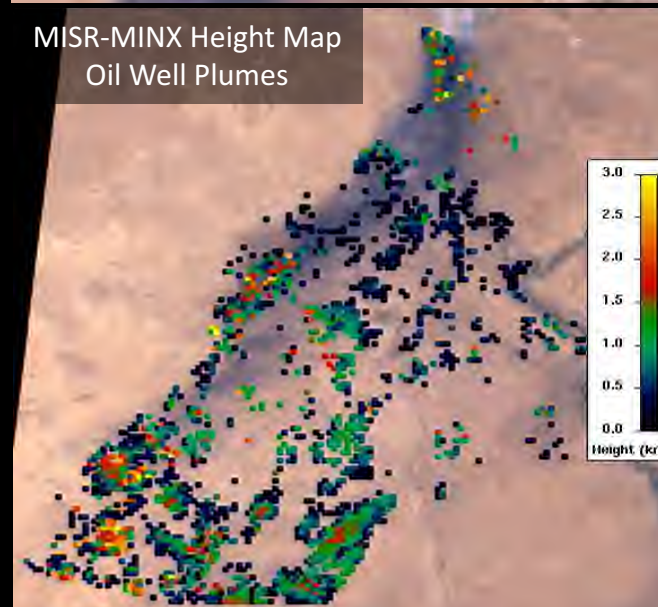


**Parallax**, the change in apparent plume position relative to the surface, as observed from the NASA Earth Observing System's Multi-angle Imaging Spectroradiometer (**MISR**) instrument, makes it possible to map the height of **smoke**, **dust**, and **volcanic plumes** near-source, where plume features are visible in the multi-angle views.

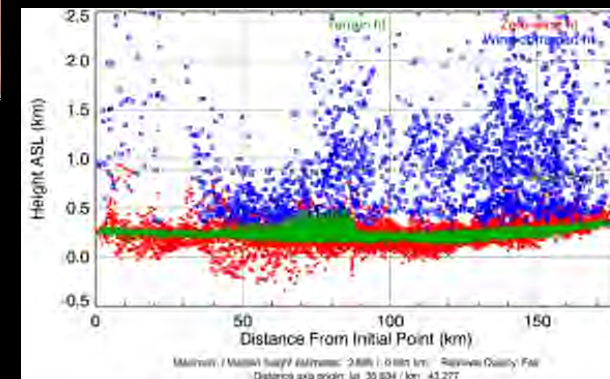
MISR-MINX Height Map  
Sulfur Plume



MISR-MINX Height Map  
Oil Well Plumes



**Zero-wind & Wind-Corrected  
MISR Height Profiles  
Downwind from Near-source**



**R. Kahn, T. Kucsera / NASA GSFC  
T. Canty, R. Bolt, CJ Vernon / U. Maryland**

# Backup Slides



# SAM-CAAM *Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

## 1. AEROSOL PROPERTIES FROM *IN SITU* MEASUREMENTS & INTEGRATED ANALYSIS

	Abbrev.	Required Variable
1	EXT	Spectral Extinction
2	ABS	Spectral Absorption
3	GRO	Hygroscopic Growth
4	SIZ	Particle Size
5	CMP	Particle Type (a composition constraint)
6	PHA	Single-scattering Phase Function
7	MEE	Mass Extinction Efficiency
8	RRI	Real Refractive Index

# SAM-CAAM *Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

## 2. METEOROLOGICAL CONTEXT

	Abbrev.	Required Variable
9	CO	Ambient Gases (CO + O <sub>3</sub> + NO <sub>2</sub> )
10	T; P; RH	Standard Ambient Meteorological Variables
11	LOC	Geographic Location

## 3. AMBIENT REMOTE-SENSING CONTEXT

	Abbrev.	Required Variable
12	A-EXT & A-ABS	Ambient Spectral Extinction & Absorption
13	A-PHA	Ambient Particle Phase Function
14	A-CLD	Ambient Cloud & Large-Particle Size/Type
15	HTS	Aerosol Layer Heights